NASA Technical Memorandum 81263 USAAVRADCOM TR-81-A-3

(NASA-TM-81263) US ARMY REMOTELY PILOTED VEHICLE SUPPORTING TECHNOLOGY PROGRAM (NASA) 13 p HC A02/MF A01 CSCL 01C
N81-18295
Unclas
G3/33 41097

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January 1981

NASA
National Aeronautics and
Space Administration

United States Army
Aviation Research
and Development
Command

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INTRODUCTION

The U.S. Army first expressed interest in the development of a small remotely piloted vehicle (RPV) for real-time target acquisition/designation and aerial reconnaissance in 1974. The Aquila System Technology Demonstrator (STD) program[1] was initiated to quantify the performance, operations, and training characteristics needed to support an Army requirement for such a system. The Aquila STD program, completed in 1978 with 219 flights and over 300 flight hours, provided the data needed to generate a Required Operational Capability (ROC). The Army RPV program subsequently progressed to the Aquila full-scale engineering development (FSED) program. This paper describes the exploratory development programs that supported the Aquila FSED program, the current emphasis on subsystems and sensors for growth capabilities to the Aquila RPV system, and future RPV mission.

The U.S. Army exploratory development program for RPVs has five major technical areas: (1) air mobility (propulsion, structures, flight control, launch, recovery, reliability, maintainability, and vulnerability/survivability), (2) radar, (3) future mission studies and tradeoffs, (4) command and control, and (5) electrooptics. If exploratory studies and feasibility demonstrations are successful, advanced development of prototype subsystems/sensors is initiated and validated through ground and flight tests.

AQUILA FSED PROGRAM

The major elements of the Aquila FSED program are depicted as operationally deployed on the battlefield in Figure 1. System elements include the air vehicle, recovery subsystem, air vehicle handler, remote ground terminal, ground control station, launcher subsystem, and maintenance shelter.

A number of supporting technology programs were essential to the definition and development of the Aquila FSED program — propulsion system development and tests, launch and recovery studies and tests, fabrication techniques, servo actuator developments, and antijam data link developments. Of these activities, only the propulsion and data link developments will be described here. Other supporting technology programs for the Aquila FSED program were described by Stanton and Smith[2] in the first meeting of this symposium in 1979.

The Aquila FSED program utilizes the Modular Integrated Communication and Navigation System (MICNS) as its antijam data link. That key subsystem provides command uplink, telemetry downlink, video downlink, and navigation of the air vehicle relative to the remote ground terminal — all in a hostile jamming environment. The major development leading to MICNS was the Integrated Communications and Navigation System[3] (ICNS) (see Fig. 2).

The primary objectives of the ICNS program were to build components (analog null steerer,

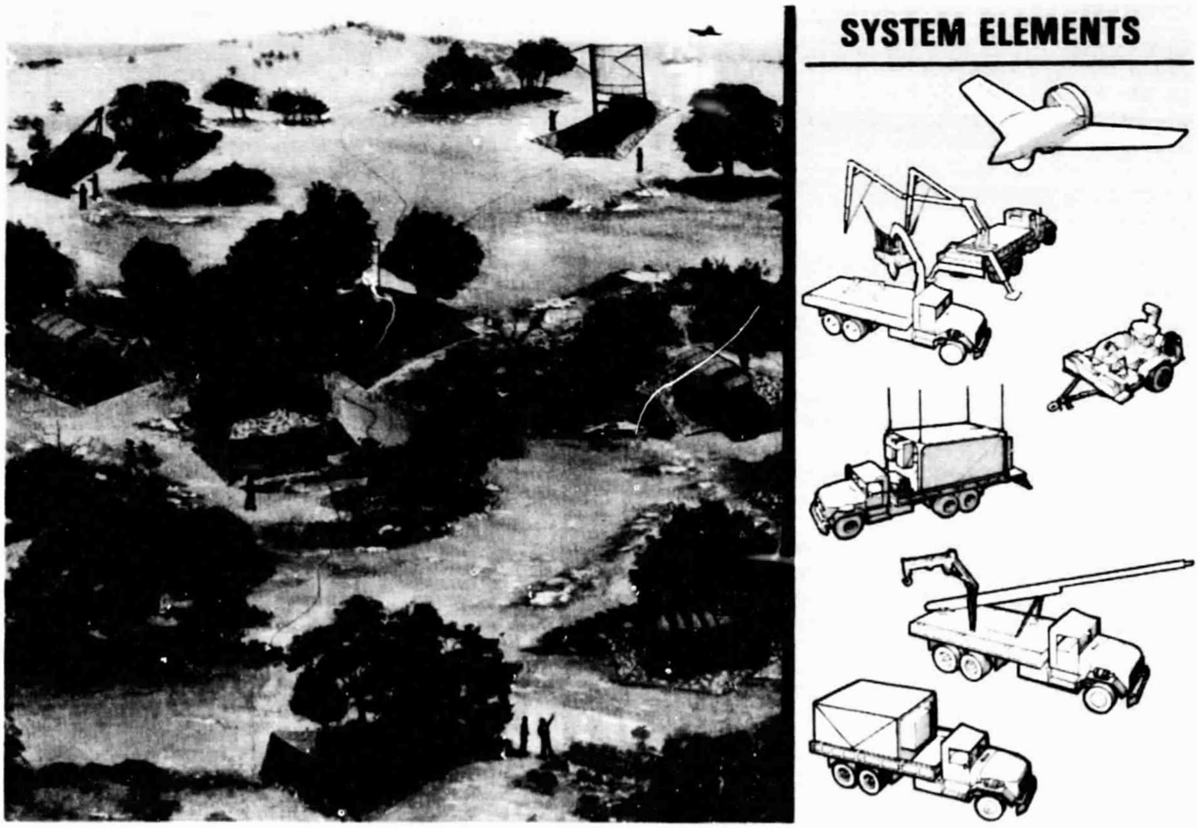

Figure 1. Deployed Aquila System

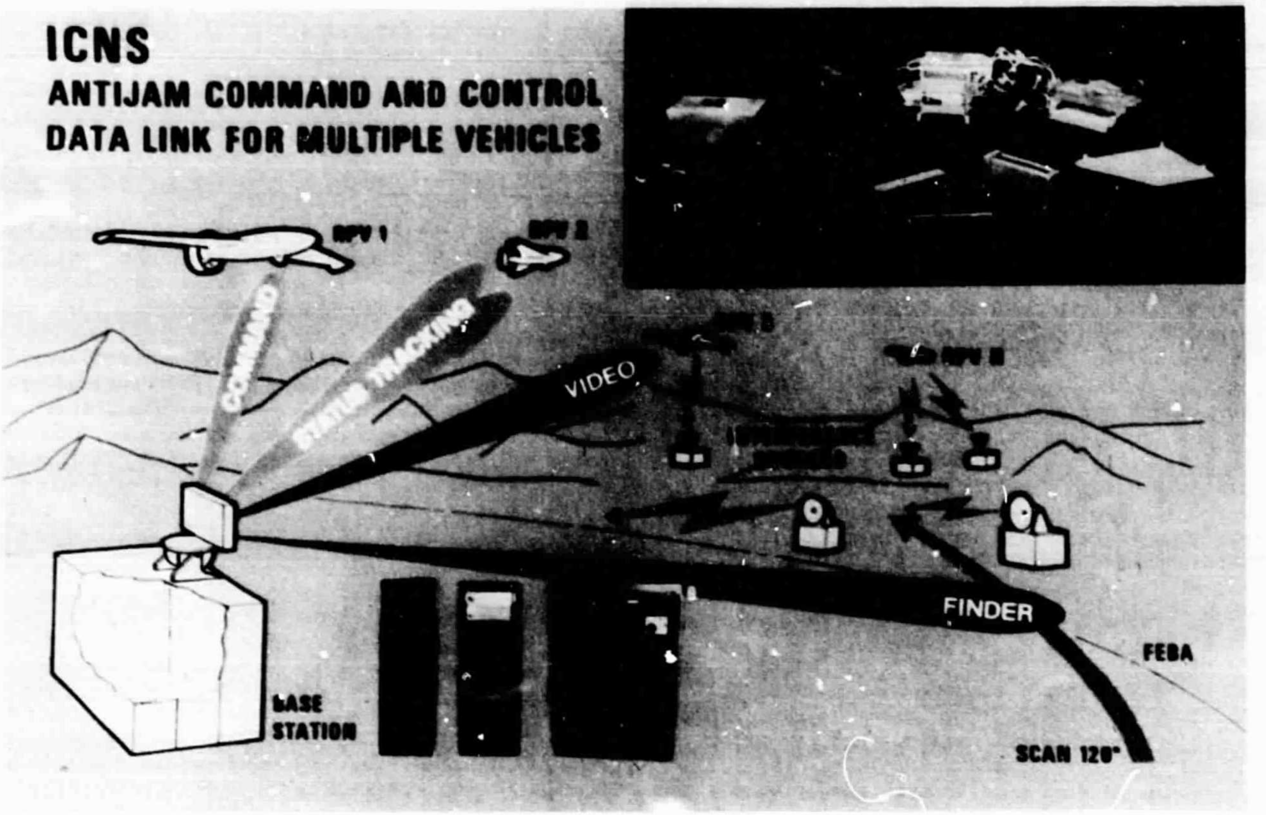

Figure 2. ICNS Scenario and Equipment

modems with chopped chirp waveforms, direct pseudonoise spread modem, and a phased array), to integrate these components with the Aquila STD system and with a manned aircraft (Otter), and to flight test and demonstrate antijam performance and multiple vehicle control.

The history of the ICNS is shown in Figure 3. That evolution required 10 years of studies, breadboard feasibility demonstrations, and hardware miniaturization and development leading to the ICNS and ultimately the MICNS. In 1970, the Harris Corporation, Electronic Systems Division, was awarded a contract by Rome Air Development Center for a study of adaptive array algorithms, followed in 1972 by a contract for a wide-band command and control modem study, and in 1973 by contracts for an RPV adaptive array breadboard and an RPV ground antenna study. Related activities were pursued by the Naval Undersea Center and RCA (video bandwidth compression techniques), the Army Electronics Command, and the Mitre Corporation. Key elements for ICNS were breadboarded in the 1973-75 period and the system was successfully demonstrated in March 1976. The next phase of the development, directed by the U.S. Army RPV Office, was to miniaturize the airborne equipment, integrate the hardware into a modified Aquila RPV system, and conduct flight tests in a simulated operational scenario. Testing was successfully completed at Ft. Huachuca, Arizona, in 1978.

Development of propulsion systems consisted of two major thrusts: engines and propellers. Two 15-kW (20-hp) class, two-cylinder, two-stroke engines were developed under contracts with Bennett Aerotechnical Inc.[4] (see Fig. 4 and Table 1) and Teledyne Continental Motors[5] (see Fig. 5 and Table 2).

A third engine developed by DH Enterprises was procured for testing by the Applied Technology Laboratory (see Fig. 6). The objective of the engine program was to test endurance, performance, altitude operation, environmental effects, noise, and electromagnetic interference characteristics for this class of engine. Measurements of horsepower and specific fuel consumption for the DYAD 280 are plotted against various output speeds in Figures 7 and 8, respectively. Other characteristics of the engine program were presented by Johnson and Gomez[6] in the Proceedings of the First RPV International Conference in September 1979.

The RPV program for propellers emphasized analysis and testing of performance, detectability, and acoustic characteristics.[7] Henry V. Borst and Associates designed and analyzed two open propellers and two ducted propellers for use on an advanced RPV. The propellers were designed for operation at 8000 rpm and at 5860 rpm. Analysis showed that at the design launch condition the ducted propellers had greatly improved performance compared to the open propellers while operating at reduced rotational speeds, thus providing a lower noise signature. The ducted propellers operated at a lower tip speed than the open propellers for either engine. Furthermore, the ducted propellers, when operating on the high-speed engine, had higher efficiency than either of the open propellers at launch and cruise conditions and nearly the same performance under dash conditions.

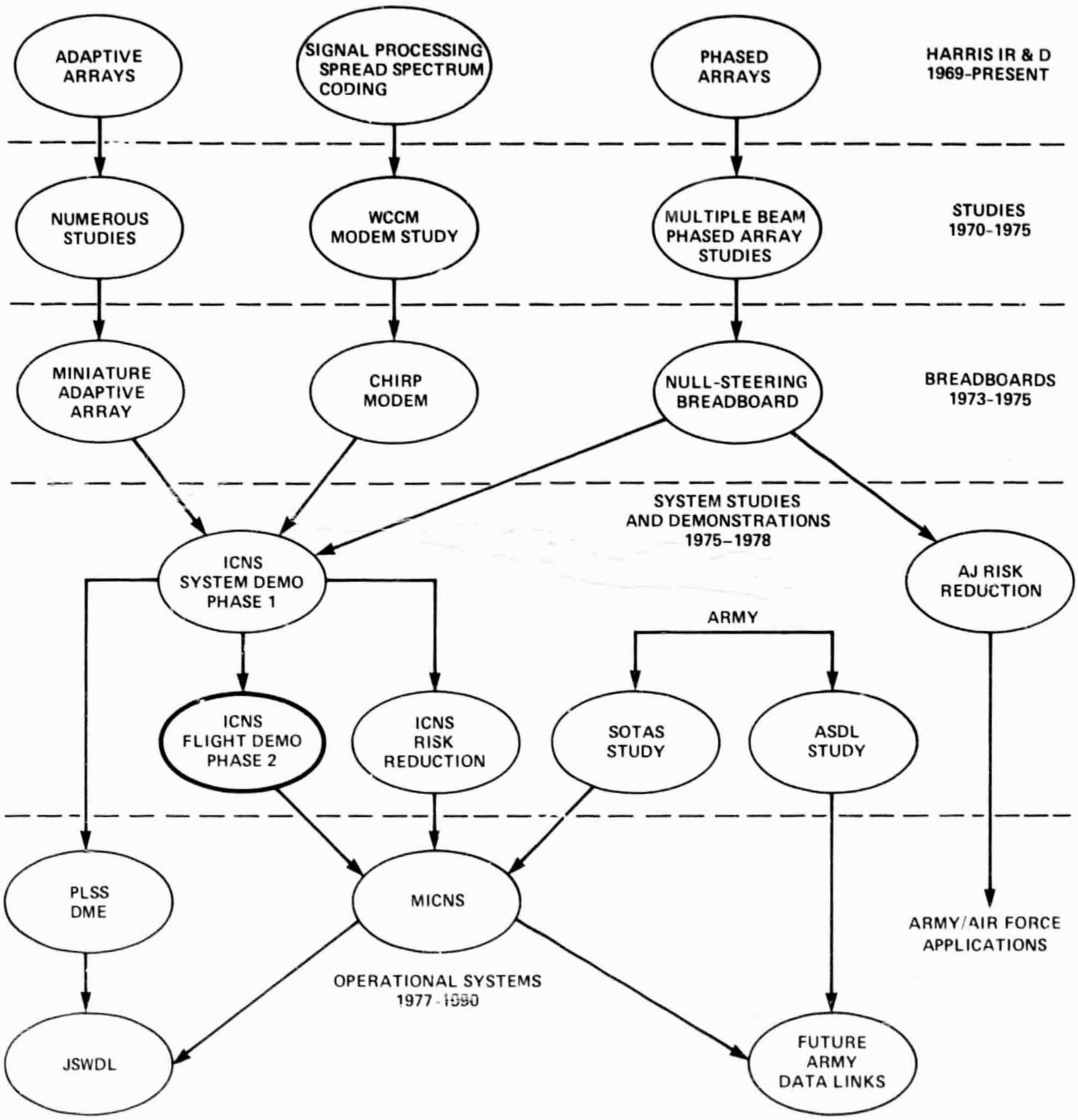

Figure 3. Evolution of ICNS

Figure 4. Bennett Aerotechnical BAT 282 Engine

TABLE 1.- BAT 282

Displacement	17.18 in.^{3} (282 cm^3)
Piston	Homelite Model 270
Power	24 hp at 8000 rpm
Weight	32 lb, including a 12-lb alternator
BSFC	0.93 at 7000 rpm
Dimensions	13.5 L × 18.5 W × 4.25 H in.
Carburetor	Two Walbro WB series

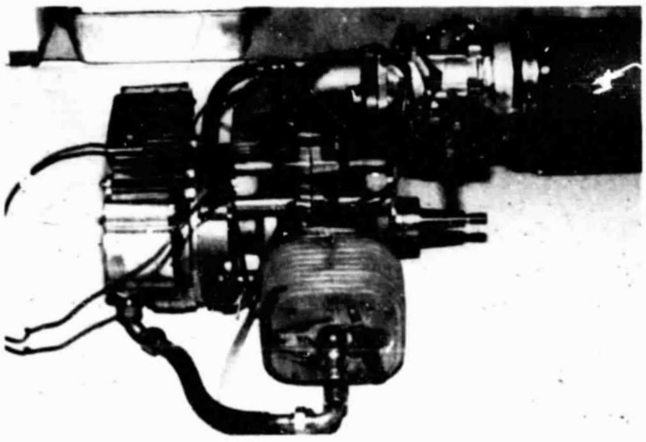

Figure 5. Teledyne Continental Mark II Engine

TABLE 2.- TCM MARK II

Displacement	16.7 in.^{3} (274 cm^3)
Piston	STIHL 090
Power	18.7 hp at 7000 rpm
Weight	26.2 lb, including alternator
BSFC	0.79 lb/bhp at 7000 rpm
Dimensions	12.6 L × 19.25 W × 8 H in.
Carburetor	HR 24A Tillotson

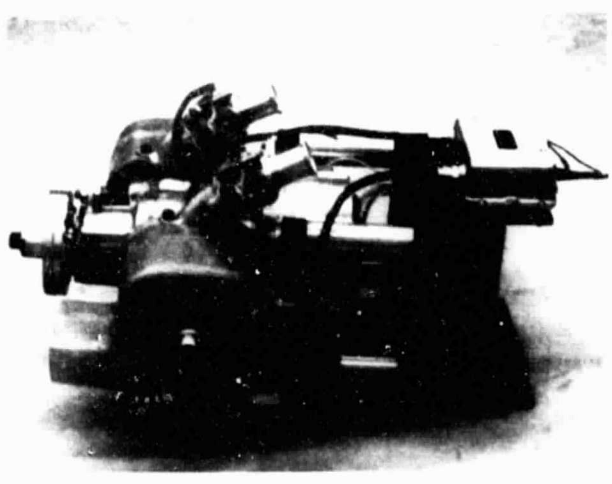

Figure 6. DH Enterprises DYAD 280 Engine

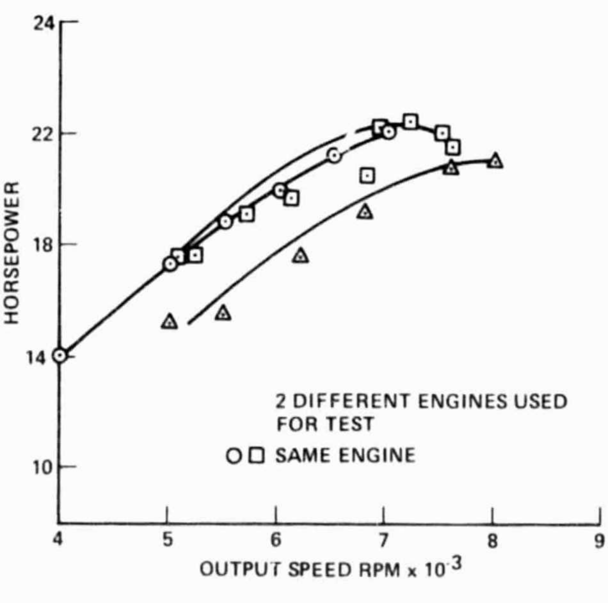

Figure 7. Engine Power — DYAD 280

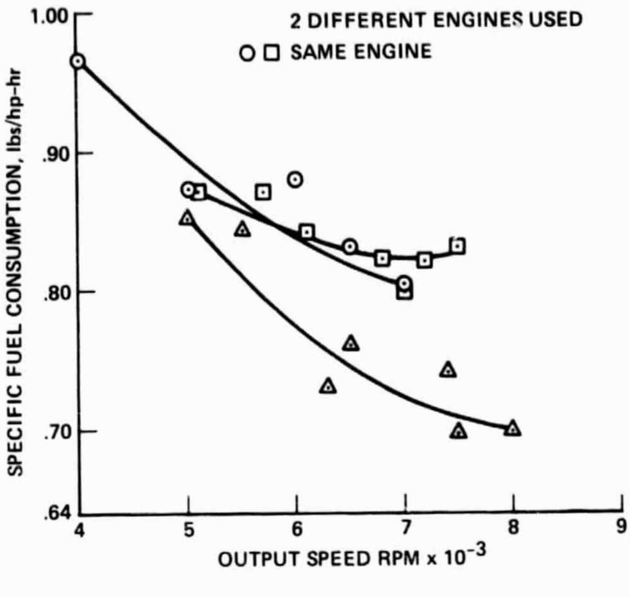

Figure 8. Specific Fuel Consumption — DYAD 280

The RASA Division of the Systems Research Laboratories conducted an investigation of the performance, noise, and detectability of RPV propellers for the U.S. Army.[8] Tests of tractor, pusher, and ducted configurations of propellers were conducted in static and simulated forward flight conditions in a wind tunnel. Design of the propellers was facilitated by use of three prediction programs: performance, noise, and aural detection. Two-, three-, four-, and six-blade configurations of five different blade designs were evaluated (see Table 3). Wind-tunnel tests indicated that forward velocity had a significant effect on the acoustic characteristics for most of the propeller configurations tested. Increasing forward velocity caused corresponding drops in the sound pressure levels from the higher harmonics. As expected, tip speed had a very strong effect on sound pressure levels and detectability. A 13% increase in tip speed from the design value of the BD3 propellers resulted in an increase of slant range detectability of 30 to 70%, depending on forward velocity. Ducted propellers were generally less detectable than their open counterparts.

AQUILA FSED — GROWTH OPTIONS

The Required Operational Capability for the Target Acquisition/Designation and Aerial Reconnaissance System (Aquila FSED) enumerated several options for growth: FLIR, multiple control, and extended range operations. Other options of interest are millimeter radar for adverse weather operations and eyesafe laser range finders for training exercises.

Exploratory development in FLIR technology included contracts to Ford Aerospace and Honeywell. FLIR systems from each contractor were tested at the Night Vision and Electrooptics Laboratory, and the Honeywell FLIR system subsequently completed flight-test evaluations in a manned aircraft at Ft. Huachuca, Arizona, in 1978.

Figure 9 depicts a POISE payload with the TV replaced by a FLIR. The gimballed system provides multiturn azimuth freedom, a Nd YAG laser, and a 6000-psi bottle of nitrogen for cooling the detectors for a minimum of 3 hr. Parameters of the FLIR are presented in Table 4. The flight-test results were encouraging and, while the program was being restructured, direction was received from the Department of the Army to close-couple the FLIR program with the Aquila FSED program. That guidance resulted in new competition and advanced development contracts to Honeywell (Lexington, Mass.) and to Westinghouse (Baltimore, Md.). Both contractors completed critical design review in the summer of 1979 and the Honeywell

TABLE 3.- CHARACTERISTICS OF DIFFERENT BLADE DESIGNS

Blade design designation	Size of the blade diameter, in. (m)	Airfoil section used	Taper ratio $\frac{C_{r/R} = 0.15}{C_{r/R} = 1.0}$	Activity factor	Amount of twist, deg	Remarks
BD1	20 (0.5048)	NACA 230XX	2.3	133	36	Optimum performance design linear chord distribution
BD2	26 (0.6604)	NACA 230XX	2.9	88	34	Optimum performance design linear chord distribution
BD3	20 (0.5048)	NACA 230XX	2	193	25	Low noise design linear chord and twist distributions
BD4	26 (0.6604)	NACA 230XX	2	193	25	Low noise design linear chord and twist distributions
BD5	20 (0.5048)	NACA 65-4XX	2	193	25	Low noise design same as BD3 except for a different airfoil section

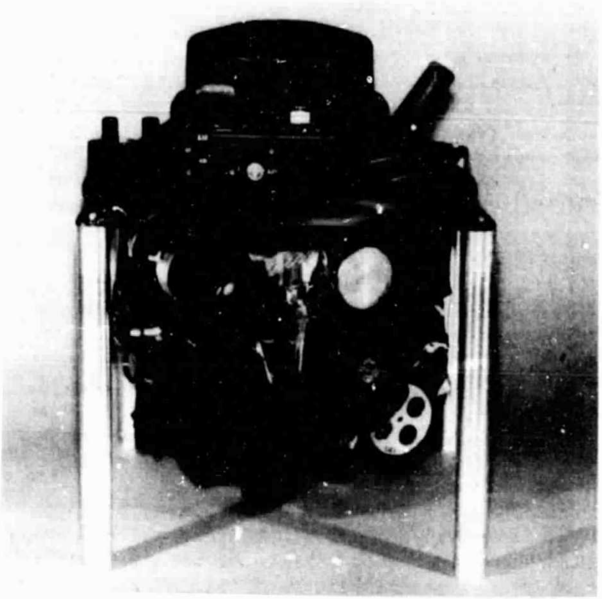

Figure 9. POISE with FLIR

TABLE 4.- FLIR SENSOR PERFORMANCE PARAMETERS

Narrow-field performance	
Total field of view	2.1° × 3.2°
Entrance aperture diameter	11.4 cm
F/number	1.22
Wide-field performance	
Total field of view	9° × 12°
Entrance aperture diameter	3.05 cm
F/number	1.22
Spectral bandpass	7.5-11.5 μm
Detector type	(Hg,Cd)Te
Cooling type	Joule-Thomson (compressed N_2)
Cool-down time	≤5 min
Frame rate/field rate	30/60 Hz
Scene rate	15 Hz

FLIR (POISE Upgrade Mission Payload System — PUMPS) is scheduled for flight tests in a manned aircraft in the spring of 1981.

Multiple control and extended range operations are being investigated through the Wideband Adaptive Ground Antenna System (WAGAS) at the Combat Surveillance and Target Acquisition Laboratory of the Electronics Research and Development Command. The WAGAS program consists of two phases: a design phase and a development, fabrication, and demonstration test phase. The primary thrust of the WAGAS program is technology development and demonstration that will ultimately provide multiple RPV control capability for the Aquila RPV system. The WAGAS will be configured to be a modular addition to the existing MICNS. As a first task in the design phase, advanced technology antenna techniques will be investigated to provide 360° azimuth coverage for multiple RPVs. The second major task for the contractors will be to propose a design that can demonstrate wideband aperture operation, 360° azimuth operation, and multiple RPV command, control, and tracking while maintaining the required antijam performance.

The U.S. Army RPV system could well utilize a surveillance sensor capable of operating in adverse weather, smoke, and dust. A 95-GHz test-bed radar has been configured for a variety of waveforms and data-processing techniques to assess the capability of the radar to locate and identify potential targets. In 1980, two ground test programs were conducted to evaluate the performance of the radar in three modes of operation: high-resolution ground mapping (HRGM), fixed-target enhancement (FTE), and clutter reference moving target indication (MTI). The first test was conducted at the Norden test site[9] (Norwalk, Connecticut) (see Fig. 10). The second test occurred at the U.S. Army Military Academy, West Point, New York (see Fig. 11).

A high-resolution ground map of the Norden test site is shown in Figure 12. Note the presence of the corner reflectors. Detectability of targets located in the ground clutter is enhanced through use of polarization diversity. Hard target returns tend to exhibit approximately the same amplitude when illuminated alternately by vertically and horizontally polarized pulses. Ground clutter tends to exhibit an amplitude variation when illuminated with alternate orthogonal polarizations. It is the amplitude modulation on the radar return, when transmitting and receiving alternate orthogonal polarizations, that is used to discriminate targets from ground clutter in the FTE mode. Figure 13 is an FTE display that demonstrates significant clutter suppression in comparison with the HRGM display in Figure 12.

In the West Point tests, most of the data were recorded on magnetic tape and analyzed on an IBM 360 computer to improve the target detection probability and, at the same time, to attenuate clutter returns. The implementation of a second threshold detector using M/N criteria was investigated. This process passes a radar signal only when M out of N outputs from the first detector are present. Figure 14 is an HRGM of the West Point site.

Ground tests of the test-bed radar have been successfully completed. The radar signal analysis has shown significant clutter rejection capabilities using polarization diversity and MTI. In the spring of 1981, the test-bed system will be flight-tested onboard a helicopter to evaluate performance under more realistic RPV operational conditions.

In September 1980, an exploratory development contract was awarded to RCA (Burlington, Mass.) for the development and test of an eyesafe laser rangefinder integrated into a LOHTADS-stabilized turret. The objective of the program is to demonstrate accurate eyesafe ranging to unenhanced targets located at distances from 200 to 5000 m under atmospheric conditions representing visibility of 9000 m. The demonstration will use a Holmium laser (2.06 micron). Tests have previously demonstrated better than 2-km noncooperative range capabilities.

FUTURE RPV MISSIONS

A rich variety of future RPV missions can be envisaged. More than 50 candidate missions have been enumerated by the U.S. Army; however, until these prospective missions have been scrutinized with regard to need, cost, and operational

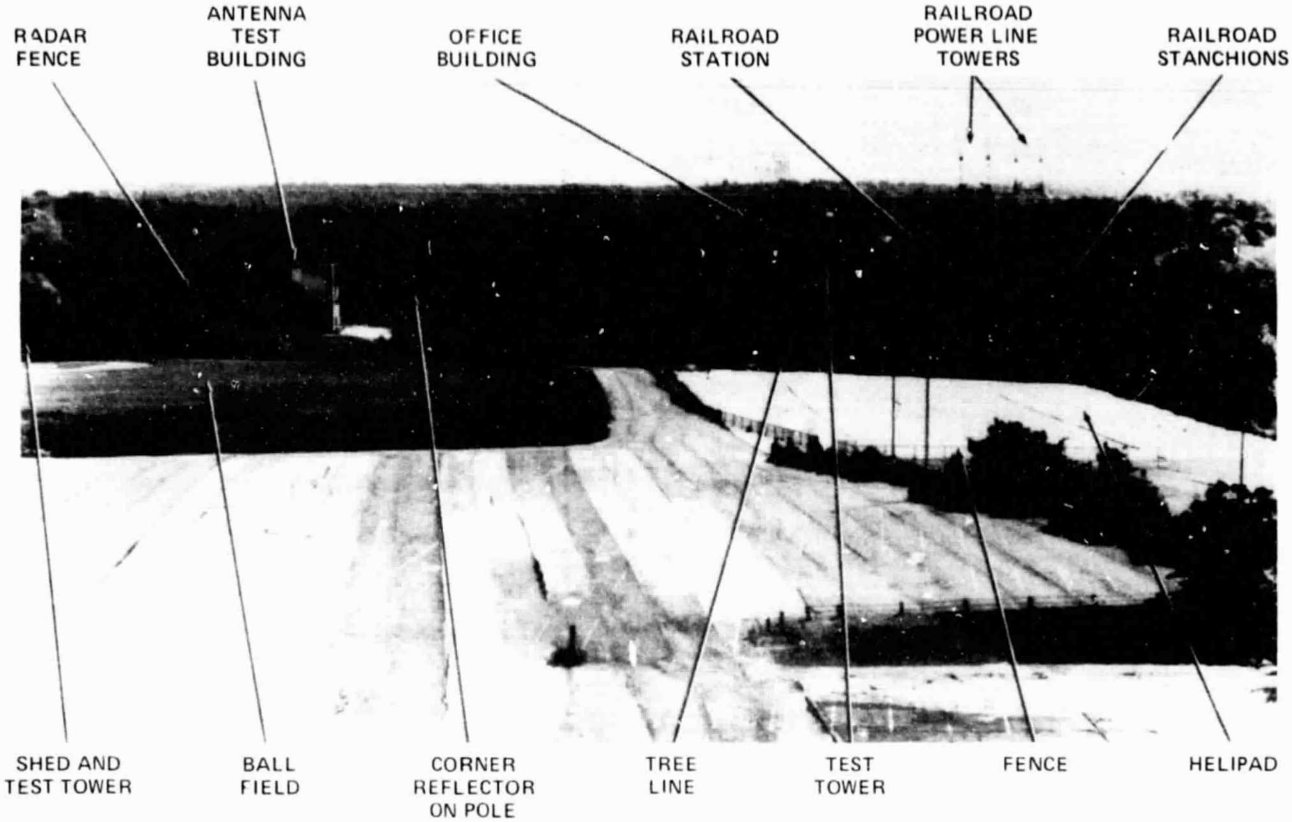

Figure 10. Norden Test Site

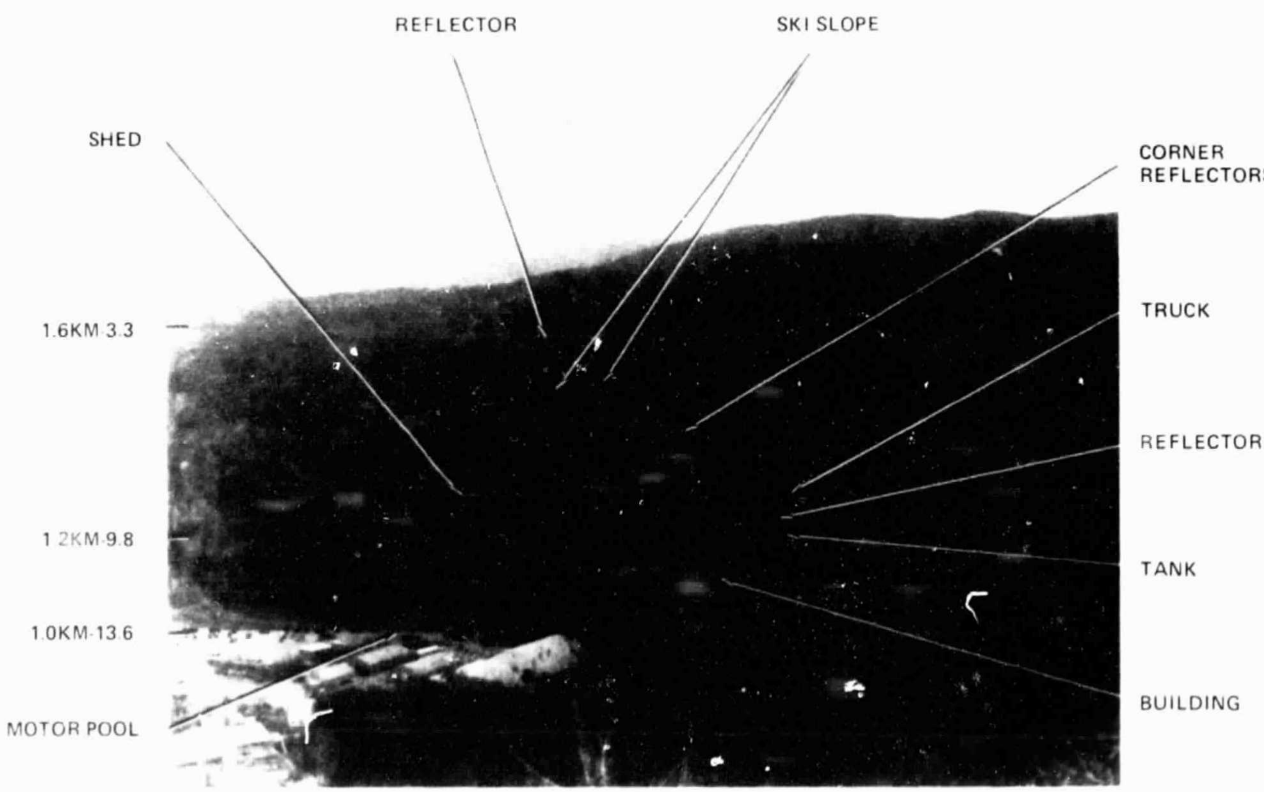

Figure 11. West Point Test Site

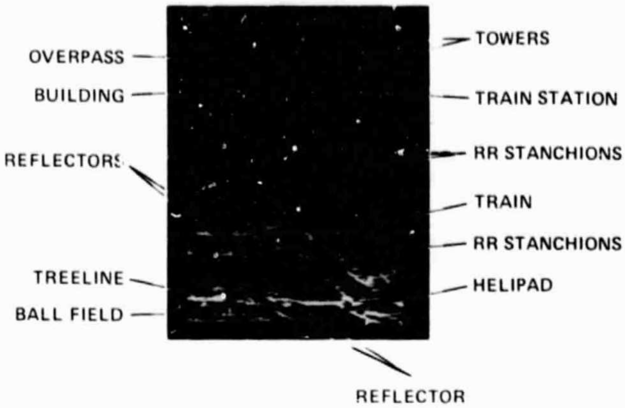

Figure 12. High-Resolution Ground Map — Norden

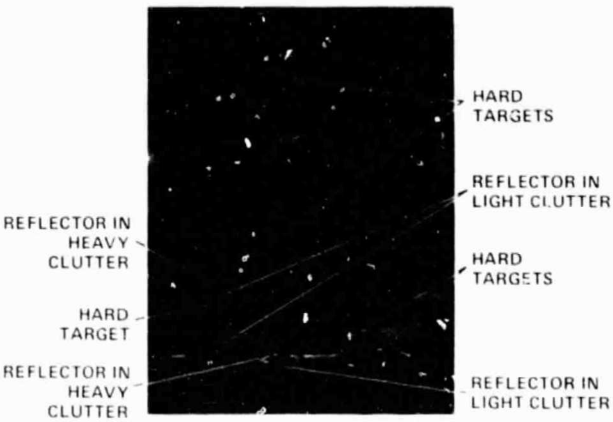

Figure 13. Fixed Target Enhancement Display — Norden

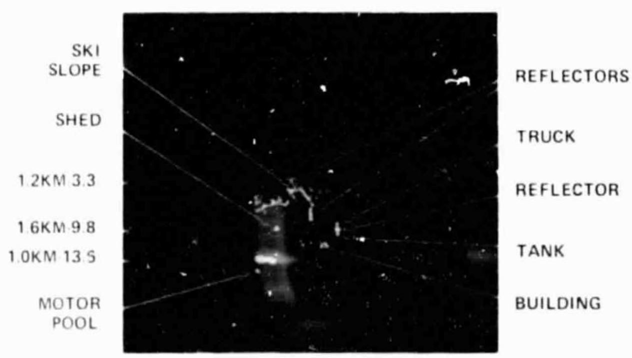

Figure 14. High-Resolution Ground Map — West Point

effectiveness, the list can hardly be considered more than a "wish list." Determination of mission need within the U.S. Army is the responsibility of the Training and Doctrine Command. Even though Required Operational Capability requirements do not currently exist for the following future RPV missions, interest is emerging for the following types and classes of future missions (see Fig. 15). The FLIR, multiple control/extended range, and radar programs were described previously.

Electronic support measures refer to missions using devices to detect, locate, and identify RF emitters. It is envisaged that such devices would

- **FLIR-NIGHT OPERATIONS**
- **MULTIPLE CONTROL-EXTENDED RANGE**
- **ELECTRONIC SUPPORT MEASURES**
- **RADAR TARGET ACQUISITION/DESIGNATION AND AERIAL RECONNAISSANCE**
- **RELAY**
- **EXPENDABLE ECM**
- **ELECTRONIC JAMMING**
- **MINE DETECTION**
- **MET/NBC DETECTION**
- **MUNITIONS DELIVERY-HARASS, MLM, SMART BOMB, ARWS**

Figure 15. RPV Future Missions

be carried in addition to the primary mission payload and would have a twofold usage — survivability enhancement and target cueing. At least two devices would probably be needed if coverage of communication and noncommunication emitters were desired.

The relay mission could take several forms: a relay for RPVs to extend operations beyond line of sight; a relay for unattended ground sensors to enable queries of non-line-of-sight sensors; and a relay for elements of single-channel ground and aerial radio systems (SINCGARS). In the latter application, the relay payload, weighing about 35-40 lb, would replace the primary mission payload. The VHF relay would have a 40-50 km range and antennas would be integrated into the air vehicle.

In the concept of expendable countermeasures, the RPV would act as a delivery system to seed designated areas with RF jammers. The expendables would be ejected from the Aquila parachute compartment. In the nonexpendable jammer mission, jammers (primarily for three bands — VHF, I, and J bands) would be carried in the normal mission payload and parachute location of Aquila.

The objective of the mine detection mission would be to detect, locate, and map hastily employed land mines through the use of line scanners or possibly an adaptation of a high-resolution FLIR.

Detection and measurement of meteorological, nuclear (radiac), biological, or chemical activities will necessitate the use of specialized sensors. The radiac and meteorological sensors appear to be compatible with the Aquila primary mission; however, biological and chemical measurements may warrant a dedicated RPV for that function alone.

The concept of munitions delivery by RPVs can be exercised in a myriad of ways. Smart expendable RPVs can be configured to home on RF, TV, or IR, e.g., the harass or the antiradiation weapon system (ARWS). Smart recoverable RPVs can carry smart weapons, e.g., smart bombs or the multipurpose lightweight missile (MLM). Smart recoverable RPVs can carry dumb (ballistic) weapons. In one investigation of this latter concept, a small RPV was configured to carry 14 Vipers or four 2.75-inch rockets[10] (see Fig. 16).

Each future mission concept has advantages and disadvantages — cost, reliability, lethality, survivability, and effectiveness — and the tradeoffs must be determined by the user and developer alike. Prospective RPV missions should be examined, analyzed, and modeled to establish the most important features and to quantify benefits.

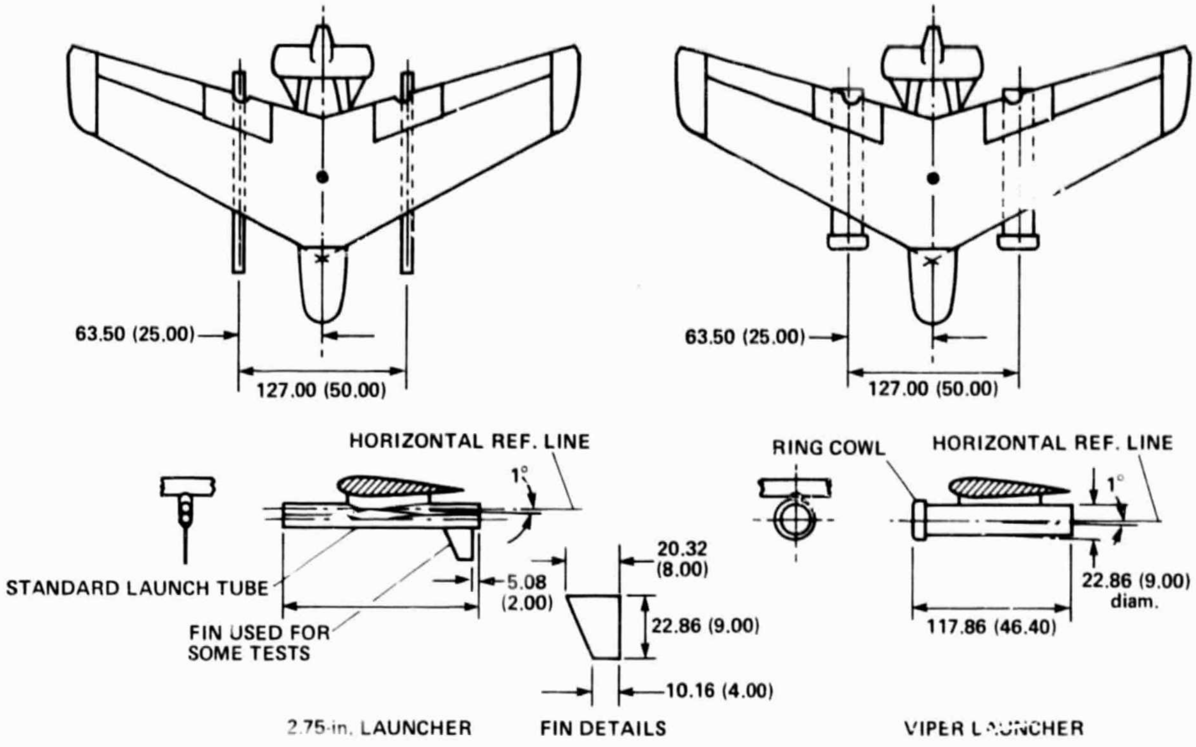

Figure 16. Strike RPVs (linear dimensions in cm (in.)).

CONCLUDING REMARKS

This paper has presented a summary of the supporting technology efforts leading to the Aquila FSED RPV program, the current programs for developing growth options (FLIR, multiple control/extended range, radar, eyesafe lasers) for the Aquila RPV system, and a brief review of emerging future RPV missions.

Future RPV systems for the military will be in competition with many other emerging weapon and sensor systems; users and developers of the new RPV systems should strive to maximize the cost and operational effectiveness of these promising systems.

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